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Protecting threatened species from coastal infrastructure upgrades: The importance of evidence-based conservation

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ABSTRACT

Increased coastal development and rising sea levels as a result of continuing climate-change put coastal regions at risk from flooding and inundation. A common mitigation response is the construction and upgrade of hard coastal protection structures, such as breakwaters, seawalls, and groynes. The alteration of the coast, together with the introduction of novel materials into coastal waters can negatively impact adjacent habitats and associated organisms. The implementation of management plans that involve scientists, as well as a variety of other stakeholders offer an opportunity to minimise adverse effects to biodiversity or even enhance it, while still protecting infrastructure and people. This study examines the management of an Australian breakwater upgrade and the progressive design finding process, including stakeholder engagement, determination of assessment criteria, and environmental impact assessment. In the course of the latter, scientific research led to the rediscovery of a presumed extinct algal species, *Nereia lophocladia*, which created an additional challenge and temporarily halted the upgrade. To accommodate this, the breakwater design solution was modified to avoid any impacts on the algal population and, in order to maximise the species' survival, novel ecological engineering approaches were proposed as mitigation strategies. Our case study underpins the value of evidence-based conservation and cooperation among stakeholders as important tools for minimising ecological impacts from coastal infrastructure upgrades.

1. Introduction

A large amount of the world's population is concentrated on the coast, making it an economically and socially important area (Harvey and Caton, 2010). As human populations increase, there is an intense pressure to protect infrastructure and coastal assets from environmental factors, such as coastal erosion (Bilkovic and Mitchell, 2013) and inundation (Jackson and McIlvenny, 2011). Installation and maintenance of coastal protection infrastructures, such as breakwaters, seawalls, and groynes are undertaken to safeguard coastal assets from storm tides and wave run-up (Arns et al., 2017).

As well as new coastal protection infrastructure, existing structures will likely need to be upgraded and regularly maintained to cope with rising sea levels related to climate-change (Gordon, 2014; Rahmstorf, 2007). The extent of future sea-level rise is somewhat unclear (Nicholls et al., 2011) and, in order to deal with uncertain future scenarios, coastal protection approaches need to be robust, safe, adaptive, and cost-effective (Spalding et al., 2014). Decision-making tools, such as cost-benefit analysis, which take into account investment and maintenance costs, as well as damage avoided by installing protection structures, can help to develop viable long-term management strategies and inform design criteria for upgrading coastal protection infrastructure (André et al., 2016). Nonetheless, social considerations, such as visual impact criteria or public access, as well as environmental impacts also need to be considered when developing coastal protection strategies (Bouma et al., 2009).

Coastal protection structures replace and fragment natural ecosystems (Cheong et al., 2013; Moreira et al., 2006), subsequently (positively or negatively) affecting the structure and function of coastal environments, both on local and regional levels (Aguilera, 2017, in press; Airoldi et al., 2005). Coastal ecosystems and the well-being of people are linked through the provisioning of ecosystem services (Menzel and Teng, 2010). Benefits to human well-being derived from ecosystem services are, however, often less tangible and comprehensible than immediate economic interests (Kansky and Knight, 2014). These often conflicting interests highlight the importance of a

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constructive multidisciplinary approach to environmental decision making, which is characterised by horizontal linkages among user groups at the same level of organisation, as well as vertical linkages across levels of organisation, such as stakeholders and Government. Such co-ordinated joint actions, associated with adherence to legal environmental protection statutes which help build a consensus among stakeholders, can lead to a path of problem-solving alternatives (Berkes, 2009) that are environmentally friendly, yet still satisfy engineering performance requirements (Naylor et al., 2017). However, problem-solving requires an accurate identification of the environmental issue in the first place. Problem identification amplifies the importance of evidence generated by scientific research because it minimises uncertainties that can bias decision-making.

In the present paper, we use an example of a coastal breakwater upgrade from Australia to demonstrate how the joint action and co-operation of multiple stakeholders and implementation of evidence-based conservation can help solve complex socio-ecological disparities involved in coastal protection infrastructure upgrades in response to sea-level rise. Given future predictions for continued rising sea levels and increasing frequency and magnitude of storms (DCC, 2009), this case study may have direct relevance to current and future coastal developments in many parts of the world.

2. Coffs Harbour breakwater upgrade as a case study

More than 80% of Australia's population lives within 50 kilometres of the coast (Trewin, 2004). This zone, which includes low-lying coastal land and adjacent marine ecosystems (McInnes et al., 2016), is socially, economically, and environmentally significant (Bennett et al., 2016). The Coffs Harbour region on the east coast of Australia annually attracts over 1.5 M visitors (Wray et al., 2016). The foreshore is dominated by two large breakwaters, which create a marina and sheltered embayment for a jetty (Fig. 1a). The Coffs Harbour northern breakwater, originally built in 1924, provides the only land access to Muttonbird Island, a Nature Reserve and an area of cultural significance to indigenous traditional owners, with commanding views of the coastline, town, and mountains. Consequently, the breakwater is heavily used by pedestrians. The breakwater is also the main protective feature for a large marina that hosts a commercial fishing fleet, commercial tour operators that access the nearby Solitary Islands, and many recreational yachts and boats (GHD, 2015). The breakwater has been subject to regular wave overtopping during storms (Fig. 1b), which are predicted to increase in severity with climate change (Arns et al., 2017). Overtopping can be life-threatening and damaging to infrastructure and vessels (Jayewardene et al., 2010).

To improve public safety and infrastructure protection, the responsible Government authority (New South Wales Department of Industry - Lands [DI-Lands]) planned to upgrade the existing breakwater.

2.1. Stakeholder consultation

The planning of the breakwater upgrade initially involved consultation with key stakeholders and the community through workshops, meetings, and interviews, which led to a set of priority issues that encompassed a range of functional, economic, social and environmental considerations important for the development (Main et al., 2016). The stakeholder consultation and priority issues informed the development of four basic design solutions: a submerged toe berm; an increased crest height; a deflection barrier; and a submerged artificial reef. However, it was agreed that additional upgrade solutions that combined different aspects of the four basic options would create an opportunity to focus on the most wave-exposed zones of the breakwater, while improving cost-effectiveness in the lower risk zones. As a result, four hybrid solutions incorporating a submerged toe berm were developed and each option was assessed using prioritised assessment criteria (Table 1) with cost being the prime objective, followed by overtopping performance (Main et al., 2016).

The summation of scores from each criterion resulted in a preferred option: a composite armoured berm upgrade. It consisted of a newly constructed rock berm at the breakwater toe below mean sea level (MSL) to break the force of waves and concrete Hanbar armouring (consisting of three legged single units, see Blacka et al. (2005) for more details) above MSL to absorb wave energy. To test the practical application of this preferred design, a physical model was created and evaluated under 10 year and 100 year ARI (average recurrence interval) wave conditions (Main et al., 2016). The results were used to refine the preferred design solution, especially the size and positioning of concrete Hanbars to secure pedestrian views from the breakwater.

2.2. Environmental impact assessment

Land and coastal development in New South Wales are governed by a planning system with legislated threshold triggers for the scope of environmental assessment. Infrastructure development proposals may cross thresholds based on their purpose, location, size or impact on a

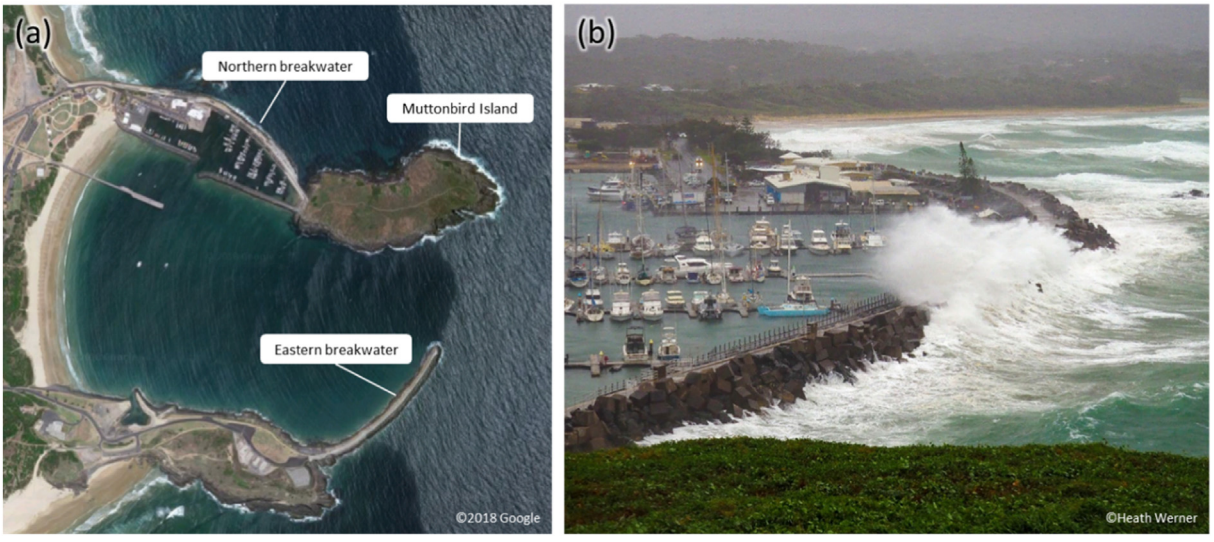

Fig. 1. Coffs Harbour marina area highlighting the breakwaters and Muttonbird Island (a), and waves overtopping the northern breakwater during a storm in 2016 (b).

Table 1
Prioritised assessment criteria for the Coffs Harbour breakwater upgrade (individual ranks in brackets). Adapted from Main et al. (2016).

- Cost (1)
- Overtopping performance (2)
- Recreational impacts (3)
- Aesthetic impacts (3)
- Ongoing maintenance requirements (3)
- Environmental impacts and approvals (6)
- Constructability (6)
- Coastal process impacts (8)
- Future adaptability (8)
- Impacts during construction (10)
- Timeframe (11)

particular value such as the presence of endangered species or cultural heritage. The environmental impact assessment pathway for the breakwater upgrade proposal involved an initial preparation of a Review of Environmental Factors, which is a structured assessment of site-specific factors, including land use zoning and potential impacts on threatened and protected species. The process of assessing impacts on a threatened species begins initially with a 'test of significance', which then may cascade into a deeper level of appraisal called a species impact assessment. Factors considered in the threatened species test of significance include whether the action proposed is likely to have an adverse impact on the lifecycle of the species such that a viable local population of the species is likely to be placed at risk of extinction.

For the Coffs Harbour breakwater upgrade, a test of significance was required for the critically endangered marine brown alga *Nereia lophocladia* (Fig. 3a), listed under the *Fisheries Management Act 1994*. This species is among only a few marine algae listed and protected globally and the breakwater and surrounding reefs are its only known habitat worldwide. As a prerequisite, a detailed population assessment of *N. lophocladia* along the breakwater was undertaken with a special focus on the population's occurrence within the construction footprint (Yee and Finley, 2015b). Underwater inspections of the area took place in 2015, with the expectation that *N. lophocladia* may not be found, as it was suggested by some to be locally extinct (Millar, 2011) given that the species has not been observed since 2002, despite numerous searches by expert scientists over the 13 year period (Yee et al., 2017). Although no *N. lophocladia* individuals were found during initial surveys in April 2015, it was not clear whether this was a result of its short macroscopic life history, rather than the actual extinction of the population. *Nereia lophocladia* displays an alternation of heteromorphic generations life history with a microscopic gametophyte and a short-lived macroscopic sporophyte (Yee and Finley, 2015a; Yee et al., 2017). Therefore, individuals might only be visible during their sporophyte phase, which is most likely in the Austral spring. With that in mind, additional surveys were conducted in September 2015 and, indeed, *N. lophocladia* sporophytes were found. Furthermore, *N. lophocladia* sporophytes have been found in subsequent surveys in August 2016 and September 2017, either as isolated individuals or in dense patches with the main habitat being natural rock (greywacke) or low profile reef on the rock-sand edge at about 2–7 m depth (Coleman et al., 2018; Kelaher, 2016). Of the population, 20% was found on the breakwater toe, of these, 90% occurred in a section of the breakwater that is characterised by the greatest water depths and also correlates with the critical section where wave overtopping is of most concern (Yee and Finley, 2015a).

Apart from direct impacts from construction works that posed an imminent risk to the *N. lophocladia* population, possible indirect impacts were also assessed, including sediment transport and hydrological conditions. However, numerical and physical modelling indicated that the extension of the existing breakwater with a submerged toe berm would have no appreciable impact on coastal processes beyond the immediate vicinity of the proposed structure (GHD, 2015).

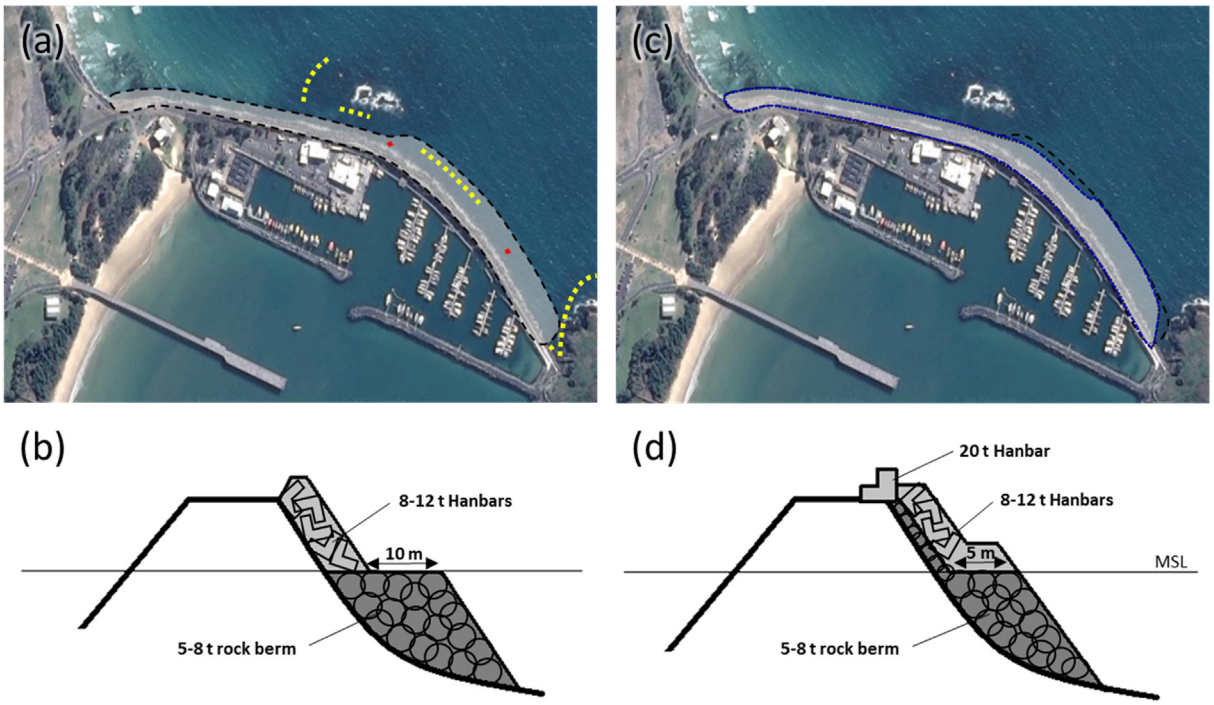

Fig. 2. Coffs Harbour breakwater upgrade: (a) Aerial extent of the initially proposed upgrade design; (b) Typical cross-section of the initially proposed upgrade design; (c) Aerial extent of the final upgrade design; (d) Typical cross-section of the final upgrade design. Black long dashed lines outline the aerial footprint of the initially proposed upgrade design. Blue short dashed lines outline the aerial footprint of the final upgrade design. Yellow (outside re-designed footprint) and red (within re-designed footprint) dotted lines mark approximate position of *N. lophocladia* threatened by the proposed breakwater upgrade in spring 2015 (not to scale). MSL: Mean sea level. Figure modified from Dengate et al. (2017) and Yee and Finley (2015a). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

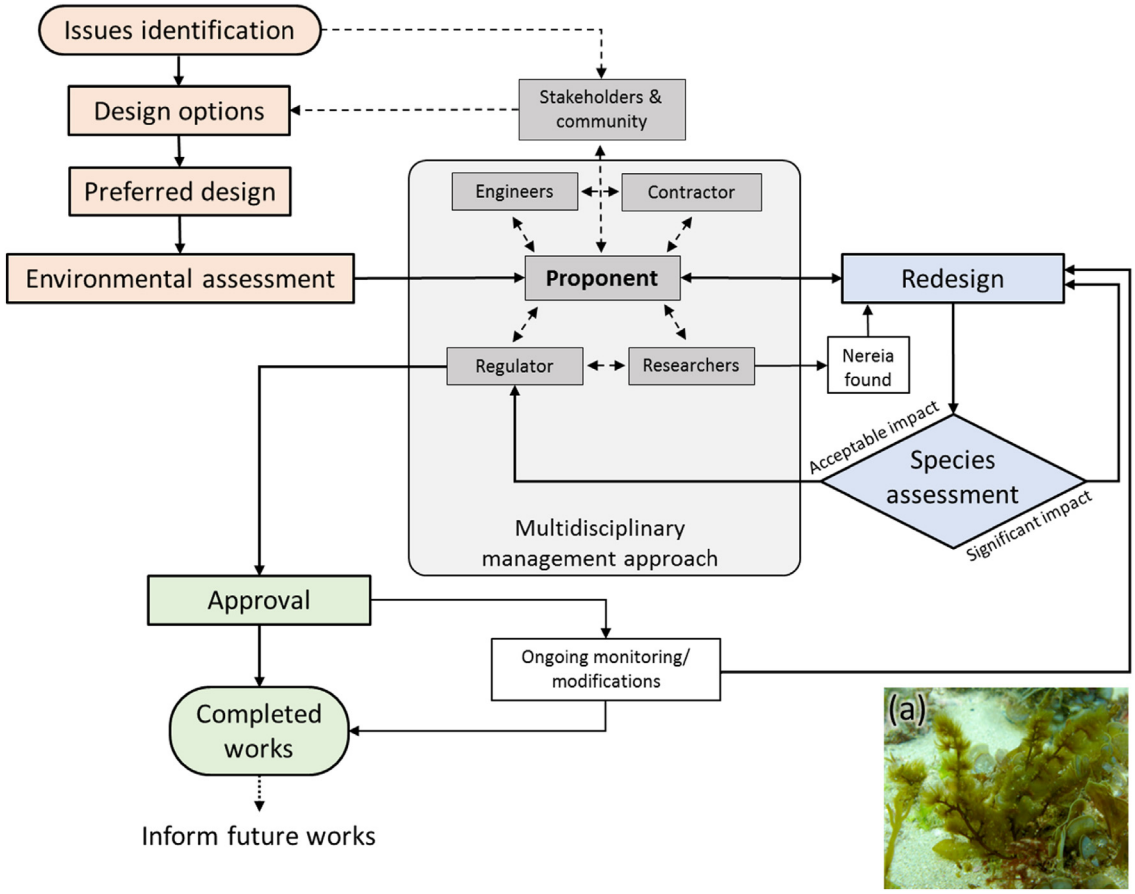

Fig. 3. Development of the Coffs Harbour breakwater upgrade. Major phases included: an initial identification of issues by the proponent (DI-Lands), the community and stakeholders to develop a preferred design which was assessed for its environmental impact (red); a multidisciplinary group spanning the proponent, engineers, environmental researchers and the regulatory agency (NSW Department of Industry–Fisheries [DPI-Fisheries]) developing an approach for redesign and identification of mitigation actions to minimise impacts on *Nereia lophocladia* (image (a) ©Elgin Associates 2015) (blue); and the proponent obtaining an approval for the works and involved monitoring, undertaking the works and assessment of design modifications that may be required (green). The approach obligates that environmental assessment and monitoring will continue beyond completion to evaluate outcomes and inform future breakwater designs. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

2.3. Impact avoidance and mitigation

The population assessment of *N. lophocladia* on and around the breakwater indicated that a significant proportion of the population would be directly affected by the planned upgrade, highlighting a need for design modifications to avoid, as well as mitigate adverse impacts on the *N. lophocladia* population. Direct impacts on *N. lophocladia* from the breakwater upgrade were able to be avoided by reducing the width of the planned rock berm at mean sea level to provide a buffer distance in areas supporting all but four recorded individual *N. lophocladia* sporophytes (99.5%) (Fig. 2). To mitigate negative impacts during construction, controlled rock placement methods were required using machine guidance software containing a detailed 3D model of existing and proposed structures to reduce putting rock incorrectly on *N. lophocladia* habitat (Dengate et al., 2017). The few *N. lophocladia* sporophytes found within the footprint of the construction works that were to be smothered and killed by rock were either translocated to more suitable habitats, collected for culture work, or preserved for genetic analysis (Coleman et al., 2017; Kelaher, 2016).

As well as modifications to minimise negative effects of construction efforts on the *N. lophocladia* population, this project created opportunities to ecologically engineer the upgraded breakwater to enhance positive outcomes for this critically endangered species, while still maintaining the integrity of the structure for its primary purpose. Thus, a collaboration among scientists, engineers, and planners came up with two suitable solutions to improve the habitat available for *N. lophocladia* in parts of the breakwater being modified: (a) providing a complex toe profile consisting of 5–8 tonne rocks every 5 m to increase the habitat where *N. lophocladia* was most abundant and (b) providing a thick layer of *N. lophocladia*'s preferred substrate (greywacke cobble) to maximise the creation of sand/rock edge habitat (Main et al., 2016). Other cases have shown that engineering new and diverse biotopes into coastal protection structures can compensate for potential negative impacts of construction works, leading to improved biodiversity values (e.g. Firth et al., 2014).

After the upgrade had been re-designed to avoid and mitigate impacts on *N. lophocladia* and maximise future habitat opportunities for its population, as well as contribute to trials of in-situ and ex-situ protection measures, the proposed works were found to be 'unlikely' to have a 'significant impact' on *N. lophocladia*. However, the period of recovery and re-colonisation of new habitats created by the upgrade is unknown, and the loss of individuals is likely to affect subsequent recruitment beyond one season (Yee and Finley, 2015a). The final development approval for the Coffs Harbour breakwater upgrade was the requirement for a robust ecological monitoring program over the next five years to determine any impacts of the breakwater upgrades on *N. lophocladia* and to measure the success of the modifications on its recruitment and survival. These outcomes can provide guidelines of standard practice for similar projects.

3. The importance of sufficient evidence

The finding of *N. lophocladia* on and around the breakwater triggered the prioritisation of minimising impacts on its population, alongside cost and performance of the infrastructure (Fig. 3). This was due to the species' status as 'critically endangered', which provides maximum legal protection, despite the perception that algae are not the most charismatic taxa. However, initial planning for the breakwater upgrade occurred during a period when *N. lophocladia* had not been recorded for 13 years (Yee et al., 2017) and was suggested by some to be locally extinct (Millar, 2011). While the review of environmental factors was mandatory and addressed a wide range of potential environmental impacts, the initial threatened species test of significance for *N. lophocladia* was prepared following the April 2015 survey, which failed to find the species. Based on the available data, which were relatively limited, the assessment recommended follow-up inspections during August/September 2015. Once the species was, somewhat unexpectedly, found in September 2015, surveys within and adjacent to the proposed upgrade site were used to inform further assessment and to better understand whether the range of expected and potential impacts could be managed considering knowledge gaps in the biology and ecology of *N. lophocladia.* It became evident to both the proponent and the regulatory agencies, that ongoing consultation with scientists was a necessity, as regulatory obligations create a requirement for decisions to be based on the best available evidence. Knowledge based on evidence is vital for effective conservation but pre-existing data are often scarce or, as in the case of *N. lophocladia*, insufficient and therefore error-prone. If decisions about the upgrade design had been made based on existing evidence (i.e. absence of the population), the implementation of design modifications would have been thought unnecessary and therefore could have posed a serious risk to the population's survival. In other words, *N. lophocladia*'s potential presumed extinction could have triggered its actual extinction. This highlights the general difficulty of dealing with rare or endangered species (Lindenmayer and Likens, 2018), where management decisions and conservation efforts need to be made in the face of uncertainty (McDonald-Madden et al., 2008). This uncertainty arises from the lack of data on many aspects of the ecology of endangered species, and can, in combination with other factors, lead to species being prematurely declared as extinct (Brodie et al., 2009; Ladle et al., 2011). Lindenmayer and Likens (2018) emphasise the importance of targeted surveys of endangered species, as non-targeted general biodiversity studies will not produce sufficient records. Hence, we recommend that, when there is potential for significant impacts to threatened species, management decisions should be based on relevant up-to-date scientific data and proponents may need to incorporate the acquisition of such targeted scientific data into their planning horizons.

4. Conclusion – what have we learnt?

Upgrading hard coastal protection in response to rising sea levels is necessary to protect valuable infrastructure, but will impact marine ecosystems. While it is important to minimise these impacts, future upgrades also provide an opportunity to enhance ecological benefits and therefore improve ecosystem services (Davis et al., 2017). The Coffs Harbour breakwater upgrade and findings for the critically endangered *N. lophocladia* demonstrate that design alterations and ecological engineering can contribute to conservation efforts when multidisciplinary management is utilised. However, decision-making cannot be solely based on insufficient historic evidence and beliefs, underpinning the need for adequate and targeted surveys. The ecological values of design solutions are often site-specific (Martins et al., 2015) and require evidence-based knowledge of habitats and species at risk. Therefore, potential impacts and issues for threatened species must be appropriately assessed *a priori* to developments to facilitate a detailed action plan to minimise negative effects on the environment, but also to establish what ecological values could be enhanced. Hence, conservation and enhancement of habitat adjacent to coastal protection structures are dependent on a collaboration of scientists, engineers, and other stakeholders to identify key ecological constraints and alter infrastructural designs accordingly (Schulze et al., 1996). The collaboration of key stakeholder groups and government agencies often makes finding a common ground a challenge. However, the management of the Coffs Harbour breakwater upgrade shows how parties can work together and find a compromise that balances economic values (protect infrastructure) with environmental attributes (protect adjacent habitat). Subsequently, rigorous and repeated monitoring of altered sites, evaluation of effectiveness, and, where appropriate, adaptive measures can help to create environmentally friendly solutions for the growing global demand for coastal protection infrastructure upgrades in response to rising sea levels.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.ocecoaman.2018.08.028.

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